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DESIGN, DEVELOPMENT AND ANALYSIS OF DIFFERENTIAL ANTI-REVERSE MECHANISM

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ABSTRACT

A vehicle tends to move in undesired reverse direction, while climbing an inclined slope in heavy traffic or if required to stop and restart the engine, to avoid which the driver has to perform three tasks simultaneously viz. disengaging the brake, releasing the clutch and pressing the accelerator, which becomes a tedious job. To make it easier, we intend to make use of freewheel meshed with the rear bevel pinion of the differential to be called as Differential Anti-Reverse Mechanism-DARM, which can be engaged or disengaged by control on driver's console. It will prevent the reversal motion of the vehicle in such conditions when engaged, allowing the forward motion regardless its engagement. While doing so we had performed solid modeling in PTC Creo, followed by stress analysis on the model in ANSYS, the results of which are satisfied by theoretical calculations. We had also executed the idea on the physical working model with the help of a bicycle freewheel and a wiper motor and we had got satisfactory results.

KEYWORDS: Anti-Reverse, Freewheel, PTC Creo, ANSYS

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Original Article

INTRODUCTION

When we run the car on slope then car tries to move backward, this causes problems like accident with vehicle behind it, increased effort to keep vehicle stationery on slope, decrease in life of brake shoe, increased efforts for driver, fuel consumption increase in fuel consumption. So we aim at avoiding this backward movement of a car on slope, and other listed problems consequently. We have use freewheel [6] which allow rotation only in forward direction and not in reverse direction. When vehicle is moving in forward direction freewheel will rotate and hence allow forward direction. But when vehicle is going to move in reverse direction freewheel will lock and avoid reverse direction.

While taking reverse gear on normal path freewheel will get disengaged with system and then car is allow to move in both the direction that is forward and reverse. So this is the principle that we have use to avoid reverse motion on slope and to avoid the problem arising because of it [3][4][5].

LITERATURE REVIEW

Existing Systems

In normal vehicle, with differential, when the car is taking a turn, the outer wheels will have to travel greater distance as compared to inner wheels in the same time. If therefore, the car has a solid rear axle only and no other device, there will be tendency for the wheels to skid. Hence if the wheel skidding is to be avoided, some mechanism must be incorporated in the rear axle, which should reduce the speed of inner wheels and increase the speed of the outer wheels when taking a turns; it should at the same time keep the speeds of all the wheels same

when going straight ahead. Such a device which serves the above function is called a “differential”. A differential is a device, usually, but not necessarily, employing gears, capable of transmitting torque and rotation through three shafts, almost always used in one of two ways: in one way, it receives one input and provides two outputs—this is found in most automobiles—and in the other way, it combines two inputs to create an output that is the sum, difference, or average, of the inputs.

A vehicle's wheels rotate at different speeds, mainly when turning corners. The differential is designed to drive a pair of wheels while allowing them to rotate at different speeds. In vehicles without a differential, such as karts, both driving wheels are forced to rotate at the same speed, usually on a common axle driven by a simple chain-drive mechanism. When cornering, the inner wheel needs to travel a shorter distance than the outer wheel, so with no differential, the result is the inner wheel spinning and/or the outer wheel dragging, and this results in difficult and unpredictable handling, damage to tires and roads, and strain on the entire drive train.

This invention relates to a drive mechanism adapted to drive a plurality of numbered or counting wheels such as those commonly found in use on odometers wherein the drive mechanism comprises a flexible finger which drives the counter in a forward or counting direction, but prevents driving the counter in the reverse direction.

Types of Differential

Following are the generally used differentials [7]

- **Open Differential**

The open differential is a type of differential that supplies the same amount of torque to each of the wheels of a vehicle [8]. The engine can limit the amount of traction needed on hard, dry surfaces that do not require as much. In slippery, wet or unstable surfaces, torque is applied so that traction can be achieved without risking slippage. In circumstances where one wheel has steady traction and another is at risk for slipping, the differential divides the torque between both wheels, reducing the torque for stable wheel to that of the slipping one, used in BMW.

- **Limited Slip Differential**

Limited Slip and positraction (posi) differentials are designed to "limit" the tendency of open differential to send power to a wheel that lacks traction and redirect the power to a degree to the other wheel of the axle [9]. The Limited Slip and Positraction differential will send power to both wheels equally when traveling straight, however when one wheel spins due to a lack of traction, the differential will automatically provide torque to the other wheel with traction. Used in Ford Falcon.

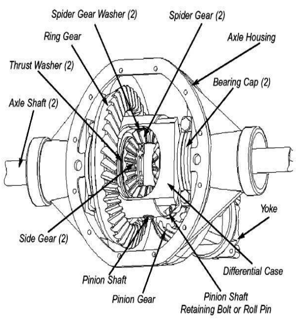

Figure 1: Open Differential

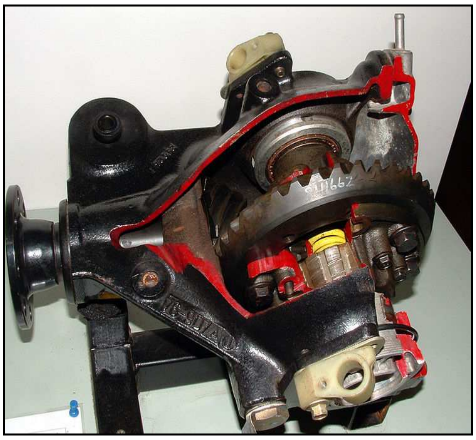

Figure 2: Limited Slip Differential

- **Locking Differential**

A locking differential may provide increased traction compared to a standard, or "open" differential by restricting each of the two wheels on an axle to the same rotational speed without regard to available traction or differences in resistance seen at each wheel [7]. A locking differential is designed to overcome the chief limitation of a standard open differential by essentially "locking" both wheels on an axle together as if on a common shaft. When the differential is unlocked, it allows each wheel to rotate at different speeds (such as when negotiating a turn), thus avoiding wheel skidding, used in Mitsubishi.

Figure 3: Locking Differential

METHODOLOGY

When a normal vehicle is moving on an inclined path in a heavy traffic or if it is stopped on the slope and then suddenly started, it tends to move backwards. This can cause an accident with the vehicle just behind. In the normal running of a vehicle we have to perform three tasks at the same time i.e. disengaging the handbrake, releasing the clutch and at the same time accelerating the car. It can prove to be difficult for a novice driver. To solve this problem, we make use of the freewheel, which is attached to the differential. This freewheel is engaged with the help of solenoid valve and is coupled with the bevel gear of the differential. The motion of the freewheel is restricted in reverse direction. So, when the vehicle is moving in the forward direction the freewheel also moves in the forward direction. But when the vehicle is moving in reverse direction the freewheel restricts the reverse motion. Hence, the accidents can be avoided.

Also, the freewheel doesn’t have to be disengaged for the vehicle to move in the forward direction. It can move in forward direction without any problem. To move in the reverse direction the freewheel has to be disengaged. To ensure whether the freewheel is engaged or disengaged a display mechanism can be used.

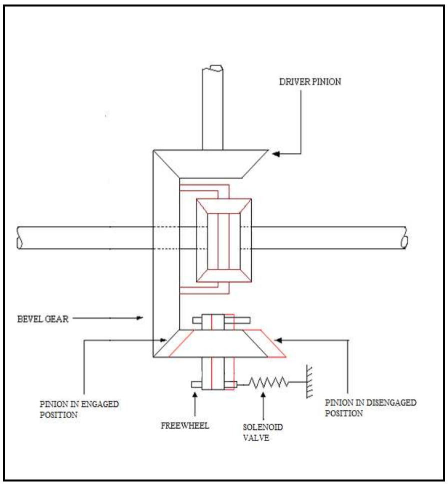

Figure 4: Schematic Diagram of Project

DESIGN

The design calculations carried out for all components are as follows[1][2]

- **Motor Specifications**

Power of Motor P=17 Nm/s

RPM of Motor n=1800 rpm

Output rpm N=24 rpm

- **Pulley Specifications**

Small End=50mm

Big End=75mm

Centre Distance=300mm

Material= CI

- **Belt Design**

T_1, T_2, μ=o.25, 2β=30°, b, t, L, T_s

T_s = P*60/2* π *n

= (17*60/2* π *24)

= 6.76 N-m

= 6.76*10³ N-mm

T_s = (T_1 -T_2)*(D_1 /2)

$6.76*10^3 = (T_1 - T_2)*(50/2)$

$(T_1 - T_2) = 269.6$ N (1)

And

$(T_1/T_2) = e^{\mu\theta cosec\beta}$

But $\theta = 180 + 2\ sin^{-1}((37.5-25)/(300))*(\pi/180)$

$\theta = 3.22$ radian

Thus

$(T_1/T_2) = e^{0.25*3.22*cosec15}$

$(T_1/T_2) = 22.47$ (2)

From equations (1) & (2)

$T_1 = 282.15$ N

$T_2 = 12.557$ N

Now

$\sigma_t = (T_1/b*t)$

We select belt of c/s "A"

$\sigma_t = (282.15)/(12.7*7.93)$

$\sigma_t = 2.80$ N/mm²

as, $[\sigma_t] = 7$ N/mm²

SAFE.

Now, $L = \frac{\pi}{2}*(D1+D2) + 2s + \frac{(D1+D2)^2}{4s}$

$= \frac{\pi}{2}*(50+75) + 2*300 + \frac{(50+75)^2}{4*300}$

L= 809.37 mm

L= 31.86"

L= 31"

We select- "A-A29"

- **Gear Design**

Design of spiral bevel gear used in the differential that is connected to the freewheel.

P=1.06 W

N_1=16 rpm

Z_1=10

Z_2=43

i=4.3

$\sum=90^0$

[P]=1.5 W

$\propto=20^0$, $\beta_1=30^0$, $\beta_2=60^0$, $\beta_{avg}=45^0$

i==$\frac{Sin\,\delta_2}{Sin\,(\sum-\delta_2)}$

Step (2)

Z_1=10

Z_2=43

Step (3):- Calculating Lewis Form Factor.

$\gamma_v=\pi y_v$-

$\gamma_v=\pi(0.154-\frac{0.912}{Z_v})$……………………………(PSG 8.50)

γ_{V1}=0.303

γ_{V2}=0.482

Step (4):- Material Selection

Material	$[\sigma_b]$	$[\sigma_c]$
Pinion 40Ni2Cr1Mo28	380	1100
Gear 15Ni2Cr1Mo15	300	950

Step (5):- Weaker Element

S_1=77.9

S_2=140.64

M_t=o.632 Nm

P= $(\frac{2\pi N_1 M_{t1}}{60})$

M_t=632.7 Nmm

$[M_t]$=940 Nmm

Step (6):- Design

Design Criteria

Design Based on Beam Strength

$m_{avg} \geq 1.15\cos\beta_{avg}\sqrt[3]{\frac{[M_t]}{\gamma_v \sigma_b z_1 \psi_m}}$------------------------PSG 8.13A

$m_{avg} \geq .8150$

$m_t = m_{avg} + (b/Z)\sin\delta$

$m_t \geq .1.714$

Ours $m_t = 4$

SAFE.

Check for Wear

$\sigma_b = \frac{0.7R\sqrt{i^2+1}[M_t]}{(R-0.5b)^2 \gamma_v b m_n} \leq [\sigma_b]$

$\sigma_b = 1.239$ N/mm² $\leq [\sigma_b]$

SAFE.

As module taken is too large, assuming safe in dynamic load & wear load.

Gear taken for freewheel is not a working gear as it is not required to transmit any torque or power or to reduce the speed so any gear of same module as Ring Gear can fulfil the purpose with a check for failure for bending and wear to be made which would be similar as Pinion Gear, so similar Pinion Gear is for the purpose.

Table 1: Gear and Pinion Dimensions

		Ring Pinion	Small Gear
Module	M	4	4
No. of teeth	Z	40	10
Bore	AH_7	20	20
Hub Dia.	B	70	60
Pitch Dia.	C	160	80
O/S Dia.	D	162.34	89.62
Total Length	F	53.92	66.59
Hub Width	H	28	35
Length of Bore	I	45	62
Face Width	J	28	28
Slant Height	L	90	90
Holding Sub Dia.	K	102.39	42.78

L-Frame Design

Material: M.S.

Axial component load,

We try for 30x30x4 mm size

M = w*(L/4)

M = 500*(930/4)

M = 116250 N-mm

σ_b = (M/Z)

But,

Z = (B^3-b^3)/6

Z = (30^3-26^3)/6

Z = 1570 mm^3

(σ_b) = (M/Z) = (116250/1570)

(σ_b) = 74 N/mm^2

[σ_b] = 320 N/mm^2

SAFE.

Weld Design

A = 0.707*s*l

A = 0.707*4*30

A = 84.84 mm^2

(σ) = F/A

= 500/84.84 = 5.89 N/ mm^2

[σ] = 21 N/ mm^2 Hence Safe.

ANSYS VALIDATION

Fea Theoretical Design

We do the validation as shown below:

Analytical Method: We analyze the following cylindrical bar as:

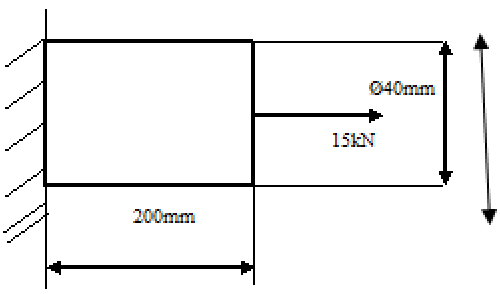

Figure 5: Axially Loaded Bar

We divide the whole domain of the problem into 4 elements, we get,

Element Matrix Equation as

$$\frac{AE}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} u_1^e \\ u_2^e \end{Bmatrix} = \begin{Bmatrix} P_1^e \\ P_2^e \end{Bmatrix}$$

For elements 1,2,3,4 (as Area, Elasticity, Length for all elements is same)

$$\frac{AE}{l} = \frac{1256.64*2.5e5}{0.050} = 6.28e9$$

Global Matrix Equation

$$6.28e9* * \begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & 2 & -1 & 0 \\ 0 & -1 & 2 & -1 \\ 0 & 0 & -1 & 1 \end{bmatrix}\begin{Bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{Bmatrix} = \begin{Bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \end{Bmatrix}$$

- **Boundary Conditions**

$U_1 = 0$, $U_2 = ?$, $U_3 = ?$, $U_4 = ?$

$P_1 = ?$ $P_2 = P_3 = 0$

$P_4 = 10000N$

On solving we get,

$U_2 = 2.59e\text{-}6$ m

$U_3 = 5.18e\text{-}6$ m

$U_4 = 7.77e\text{-}6$ m

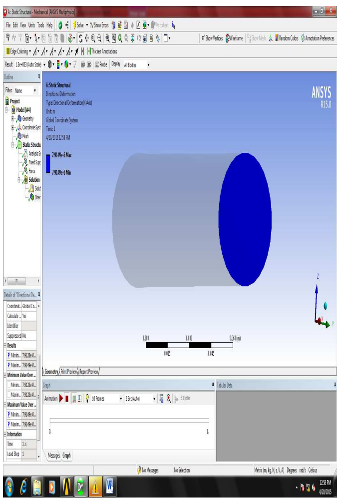

Figure 6: Ansys Validation Screenshot

Analysis in ANSYS

That is maximum deformation $U_3 = 7.9149e\text{-}6$ m

Hence validated.

Design Conclusion

From the analytical design it is found that the module required for the safe gear under the given conditions is less than 4 which is the module for the available pinion. Further the analysis of the pinion on Ansys reveals the maximum stresses to which the pinion is subjected are 1.15e7 Pa which are less than the allowable bending stress 3.8e8 Pa. Hence we finalize the same pinion gear which is of the same material and dimensions as that one with the propeller shaft as it is safe by both analytical and Ansys methods.

RESULTS AND DISCUSSIONS

Results on ANSYS

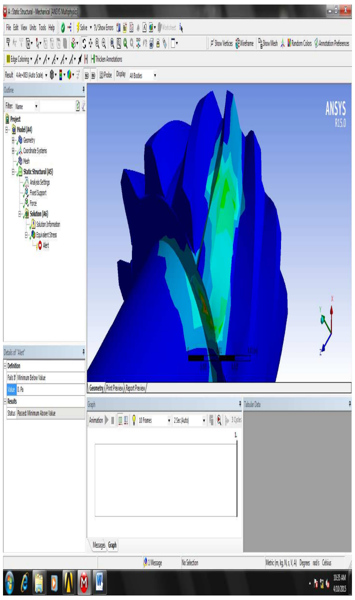

Figure 7: Ansys Analysis of Pinion Distribution of Stresses Close View

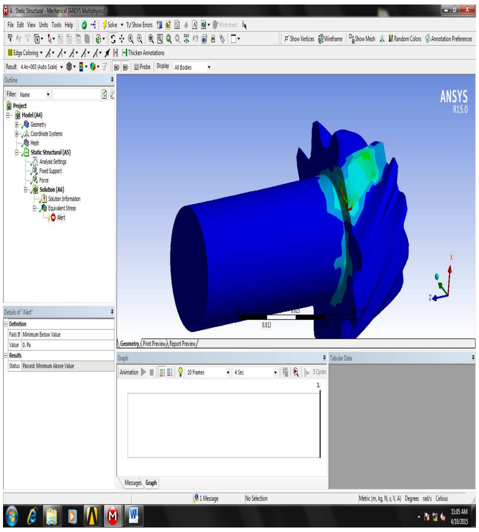

Figure 8: Ansys Analysis of Pinion Distribution of Stresses Side View

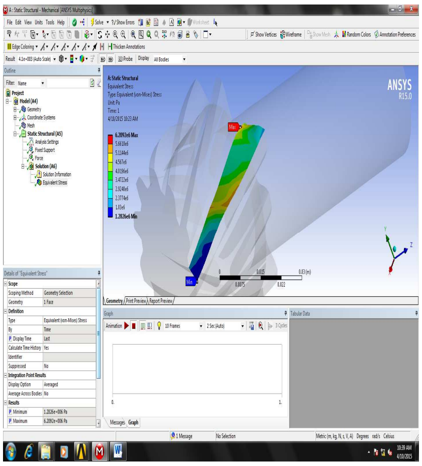

Figure 9: ANSYS Analysis of Pinion Distribution of Stresses on Surface Normal to the Load

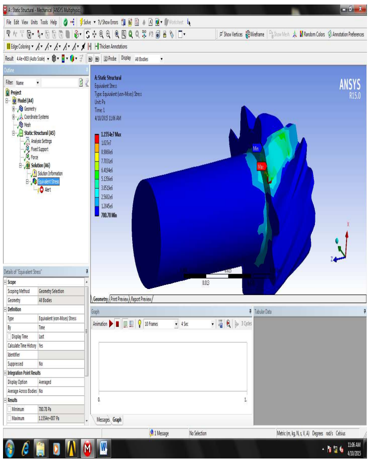

Figure 10: ANSYS Analysis of Pinion Distribution of Stresses Side View

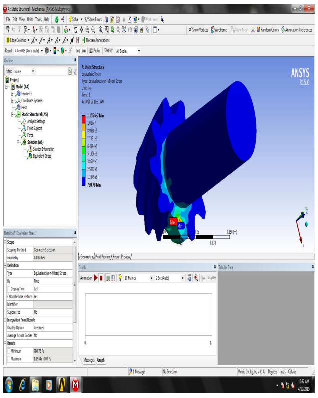

Figure 11: ANSYS Analysis of Pinion Distribution of Stresses Rear View

Results on Model

The results as observed from the working model are as follows.

For the Mechanism Installed on the Differential Under the Conditions of Motor Power 17Nm/S We Get,

- $N_{small\ pulley} = 21$ rpm ($D_1 = 50$mm)

- $N_{large\ pulley}$ = 14 rpm (D_2 = 75mm)
- $\mathbf{N_{wheels}}$= 3 rpm (Gear Ratio = 4.3)
- $N_{anti\ reverse\ pulley}$ = 14 rpm.

For Forward Motion

- **Anti-Reverse Mechanism Disengaged:**

  The rotation of propeller shaft reaches the road wheels as in normal vehicle.

- **Anti-Reverse Mechanism Engaged:**

The rotation of the propeller shaft reaches the road wheels and they travel in forward direction propelling the vehicle forward as the torque is transmitted from the differential to the back pinion to the freewheel shaft and even when the freewheel sleeve is stationary due to phenomenon of freewheeling as the saw teeth or roller becomes free of spring load and lets the back pinion and the freewheel shaft rotate even when sprocket(free wheel sleeve is stationary).

For Reverse Motion

- **Anti-Reverse Mechanism Disengaged:**

  The rotation of propeller shaft reaches the road wheels as in normal vehicle.

- **Anti Reverse Mechanism Engaged:**

The rotation of the propeller shaft does not reach the road wheels as the saw teeth or roller becomes locked due to spring pressure and both the engaged sprocket(freewheel sleeve) and freewheel shaft i.e. back pinion gets locked resulting in no rotation of the road wheels, thus putting into effect our anti-reverse mechanism.

CONCLUSIONS

After carrying out the experiment the working model functions as expected and the results are attained as forecasted. The differential anti reverse mechanism performs the function of preventing the unwanted reversal motion of the vehicle on the slopes along with the provision of the engagement and disengagement of the mechanism with the differential system of the vehicle.

The design results from analytical methods are in good agreement with the ANSYS results. Also the experimental results from working model are recorded as shown and are in acceptable limit.

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